Mapping and Monitoring Nuclear Waste Repositories with Subsurface Electrical Resistivity Arrays

Ted Asch and H. F. Morrison, University of California, Berkeley

Summary

The siting and future integrity of nuclear waste repositories is critically dependent on the local ground water regime. Electrical methods seem particularly promising in mapping and monitoring this regime since the electrical conductivity of rocks depends almost entirely on the fluid saturation, salinity and distribution. The most important recent developments in resistivity include the use of numerical modeling and resistivity mapping using subsurface electrodes. The latter yields far greater accuracy and resolution than can be obtained with surface arrays. To illustrate the power of subsurface-surface arrays we have studied an idealized two dimensional model of a nuclear repository. Since we are interested in emphasizing the anomaly caused by the repository, or subsequent changes over time in its vicinity, we have discovered that it is very useful to express the apparent resistivity results as percentage differences from either the background (for surface arrays) or from the apparent resistivities observed at a particular depth of the current source (for subsurface arrays). Percent differencing with respect to data at the repository depth dramatically reduce near-surface and topographic effects that usually confound quantitative interpretation of surface surveys. Thus, dc resistivity appears to have great potential for nuclear waste repository mapping and monitoring.

Introduction

The siting and future integrity of nuclear waste repositories is critically dependent on the local ground water regime. Electrical methods seem particularly promising in mapping and monitoring this regime since the electrical conductivity of rocks depends almost entirely on the fluid saturation, salinity and its distribution. Electrical methods have conventionally been used to simply detect the presence of good electrical conductors (e.g. sulfide orebodies) or to determine the electrical layering in ground water.

The electrical conductivity of the ground can be measured by injecting current into the ground through pairs of electrodes and then measuring the resulting voltage drops in the vicinity with other pairs of electrodes. Any or all of the electrodes can be placed in the subsurface, although traditionally surface arrays have been employed. Measurements of voltage and current for different electrode geometries are then used to infer the subsurface distribution of conductivity. These methods are indirect but ideally suited to measure the properties of a region for which it is impossible to gain direct access. The resulting interpretation of the conductivity distribution is not unique, nor does it provide high resolution of subsurface features. In many applications this latter property is to our advantage since the measurements yield bulk average values of the conductivity which often includes features that are not included in hand samples or borehole logging measurements.

Surface current and potential electrode arrays have been used for many years to determine the subsurface resistivity. The most important recent developments are the use of two and three-dimensional numerical models for interpretation, and resistivity mapping using subsurface electrodes. The latter yields far greater accuracy and resolution than can be obtained with surface arrays. This new development opens the way to more quantitative analysis of ground conductivity and offers exciting opportunities to map and monitor fluid content, temperature and fracture distribution at repository sites. To illustrate the power of subsurface-surface arrays we have studied an idealized two dimensional model of a repository to investigate the responses from conventional and borehole-to-surface arrays.

Modelling

The model is shown in Figure 1. We have assumed that in excavating and preparing the repository the water content of the rocks has been reduced so that the effective resistivity of a 100 meter thick zone has increased by a factor of three over the normal or background value (in this case 200 ohm-meters). The results of a standard dipole-dipole surface survey are presented for this model in Figure 2 as a three-dimensional perspective plot. Since we are interested in emphasizing the anomaly caused by the repository, or subsequent changes over time in its vicinity, we have discovered that it is very useful to express the apparent resistivity results as percentage differences from the background. The data in Figure 3 are the percent differences observed in the apparent resistivity relative to the 200 ohm-meters halfspace. The anomaly is diffuse and broad but quite large enough to be detected. Our experience in high accuracy field surveys has shown that it is possible to make apparent resistivity measurements with an accuracy of 0.1% For time monitoring with fixed surface electrodes the sensitivity to small changes in the repository resistivity (eg. as water reentered the zone) would therefore be quite high.

Resolution can be improved by using subsurface dipole sources and surface receiver dipoles. As shown in the model (Figure 1), the current electrodes are placed every 150 meters vertically and are treated as a series of dipole sources. The apparent resistivities measured for a given depth of the current dipole and location of surface potential electrodes are plotted vertically midway between the current electrodes and horizontally midway beneath the potential electrodes. A dramatic definition of the repository boundaries is produced by using percent differences calculated, not in reference to the background halfspace resistivity, but compared to the apparent resistivities observed at a particular depth of the current dipole source. An example is shown in Figure 4 in which all the apparent resistivities in the section are compared to the values observed with the center of the dipole source at 625 meters depth.

Differencing with respect to data at the repository depth reveals that the subsurface arrays reduce near-surface effects that usually confound quantitative interpretation of surface surveys. The results of a surface dipole-dipole survey over the repository model with a small conductive body on the surface is presented in Figure 5. The effect of the surface conductor dominates the response and is observed throughout the section. This makes it very difficult to determine the deeper structure.

In Figure 6 the results for this model are shown for the case of subsurface dipole sources and surface receiver dipoles but with the percent differences calculated relative to the apparent resistivities at the 625 meter level.

The effects due to the surface conductors have been almost entirely eliminated. In fact, comparing Figure 6 to Figure 4 in which no surface conductors were present, we see that they are virtually identical. This example illustrates the power of relative percent differencing to remove unwanted near-surface effects. This technique also eliminates 'anomalies' caused by topographic features.

In summary, dc resistivity mapping with combinations of surface and subsurface electrodes appears to have great potential for repository mapping and monitoring. Much work remains to be done in selecting the best array geometries for sensitivity in mapping features of interest in site studies.

One of the most exciting possibilities is to investigate the use of these methods to resolve the fracture-induced anisotropy. The simple illustrations above used two dimensional models with isotropic resistivity. We have three dimensional models in which fracture anisotropy could be introduced, and this, coupled with two dimensional surface arrays of potential electrodes, would undoubtedly greatly improve the resolution of interest in site studies.

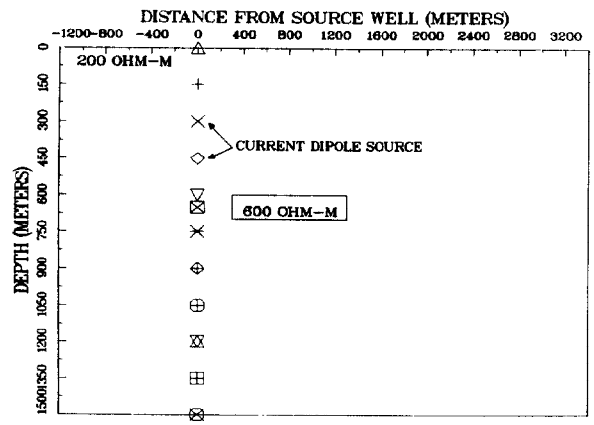

FIG. 1. Idealized model of radioactive waste repository site. Symbols represent current electrodes in subsurface dipole configuration.

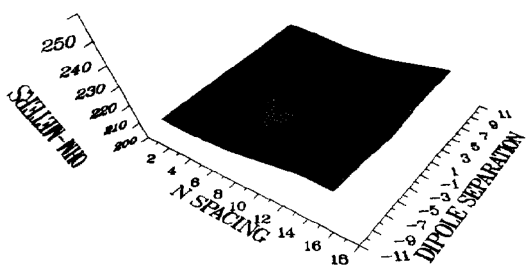

FIG. 2. Dipole-dipole apparent resistivities for model in Figure 1 from a 3-D perspective. "Dipole separation" refers to location of dipoles relative to center of model.

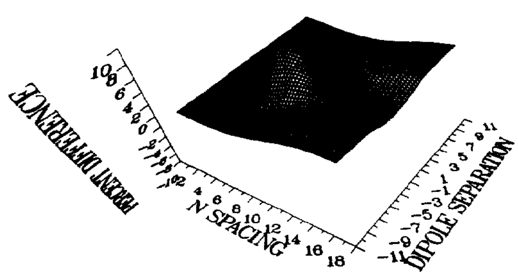

FIG. 3. Percent difference perspective view between surface dipole-dipole apparent resistivities for model in Figure 1 and background resistivity, 200 Ω-m.

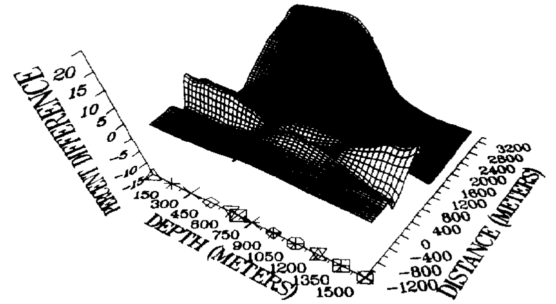

FIG. 4. Percent differences using borehole dipole sources referenced to apparent resistivities obtained with current dipole at 625 m depth.

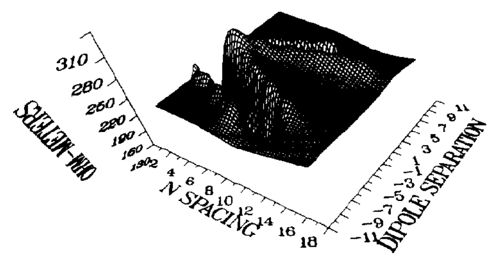

FIG. 5. Dipole-dipole apparent resistivities over a repository having a conductive (50 Ω-m) surficial body.

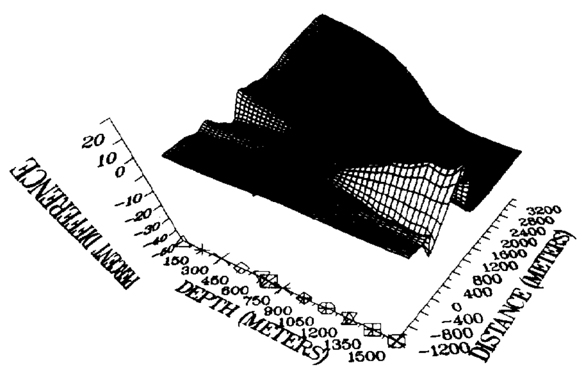

FIG. 6. Percent differences for conductive near-surface model using borehole dipoles referenced against data from 625 m depth.